EASA
European Aviation Safety Agency

Research Project EASA.2010.FC10 - SC.04

Studying, sAmpling and Measuring of aircraft ParticuLate Emissions III

Specific Contract 04

SAMPLE III – SC04

12 July 2013

An agency of the European Union

EASA.2010.FC.10
Specific Contract N^{o}: SC04

SAMPLE III: Contribution to aircraft engine PM certification requirement and standard Second Specific Contract– Final Report

12th July 2013

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Executive Summary

This report details the methods, results and conclusions of the project entitled "SAMPLE III: Contribution to aircraft engine PM certification requirement and standard". This project was funded via the European Aviation Safety Agency (EASA) under the Specific Contract N^{o}: **SC04** Implementing Framework Contract N^{o}: **EASA.2010.FC10**. The purpose of this specific contract is to upgrade the EASA owned APC (AVL Particle Counter Advanced) to comply with SAE AIR6241.

In order to deliver the aforementioned objective it was necessary to perform the following task namely;

- Exchange the CPC contained in the APC with a compliant one.

To deliver the above task parts were performed which are detailed below.

- Transport APC to AVL List Gmbh (Graz, Austria)
- AVL liaise with TSI to provide upgraded and calibrated CPC to AIR6241 specifications
- AVL to provide document evidence of upgrade and is SAE AIR6241 compliant
- APC is shipped back to the consortium

Key results from this study:

1. The EASA owned particle number measurement device within the AVL APC was upgraded to meet SAE AIR6241 specifications.
2. In conjunction with Task 3 SAMPLEIII SC03, the non-volatile number measurement in the European reference system will be SAE AIR6241 compliant.

1. Introduction

The global effects of aircraft PM emissions are a key concern from the point of human health and climate change. Controls on aircraft emissions and maintaining compliance for local air quality standards on European airports is expected to be a significant issue in some cases. Whilst significant effort is being made to identify, quantify, model and predict these effects there is still a sizeable amount of development work required to produce a working specification for the absolute measurement of emissions of PM. Both mass and number emission concentration will need to be measured in a format that can act as a standardised test under engine certification conditions. Other known aircraft emission challenges include accurate, traceable quantification of volatile emissions, especially aerosol precursors.

Control of PM emissions is one of the top priorities of the ICAO/CAEP (Committee on Aviation Environmental Protection). As a first step towards establishing a non-volatile PM Standard, CAEP, in 2010, remitted its Working Group 3 (WG3) to:

> "Evaluate and document sampling and measurement methodologies for aircraft engine non-volatile PM emissions. Note input from SAE-E31." [Remit E18.01]
>
> "Develop an aircraft engine based metric and methodology for application as a non-volatile PM emissions certification requirement for new engine types." [Remit E18.02]
>
> With a target date of February 2013.

Furthermore there is an expectation that CAEP will have developed an International Standard for PM by the end of its next 3 yearly cycle [2016].

WG3, with support of EASA and other Regulatory Agencies (Swiss FOCA, UK CAA, US FAA, Transport Canada & US EPA) requested the SAE E-31 to provide a non-volatile PM mass and number Aerospace Recommended Practice (ARP) document ready for formal approval by ballot of E31 members (a 'ballot-ready document') by February 2013. The SAE E-31 PM sub-committee has been working on developing appropriate sampling and measurement methods for aircraft non-volatile PM emissions, but has expressed severe reservation about meeting the time scale requested by CAEP for a fully developed document.

EASA funded a 1 year study (known as the SAMPLE project), commencing in October 2008, which was one of the first collaborative programmes designed to evaluate the applicability of a number of modern measurement techniques whilst assessing the nature of PM. Conclusions from the original SAMPLE programme (EASA.2008.OP.13, 2009) suggested that calibration of the measurement techniques is critical. EASA then funded another year's study (SAMPLE II), which commenced December 2009. This collaborative effort was to determine the effect of the sampling line, in terms of its construction and operation on the exhaust sample being presented to the analysers compared with the exhaust sample at the engine exhaust plane. Conclusions from the SAMPLE II study (EASA.2009.OP.18, 2010) noted that sample line residence time appears to be a key parameter to PM losses and that VPR efficiency is difficult to analyse and hence a specific lower size PM cut-off may be required to reduce uncertainty. EASA then funded Specific Contract 01 (SC01) within SAMPLE III, a 4 year frame-work contract (EASA.2010.FC.10) commencing December 2010. This work developed a concept sampling system in terms of components, manufacture and operability.

Whilst previous studies during SAMPLE & SAMPLE II have quantified the nature of PM and the interaction between PM and the transport process used to convey it from the point of generation to the point of measurement, and SAMPLE III (SC01) developed a robust well defined sampling system which has been adopted as the SAE E31 concept for PM sampling.

SAMPLEIII (SC02) compared two nominally identical SAE E31 AIR6241 compliant systems. Based upon this, and other international work, SAE E31 developed a measurement standard (AIR6241) for non-volatile Particulate Matter measurement for aircraft engines.

Task 3, in progress within SAMPLEIII SC03, is to construct and validation of a AIR6241 compliant European reference sampling system to provide confidence in system measurement uncertainty/repeatability via intercomparison with other AIR6241 compliant systems, and also could be used to obtain additional engine PM datasets. A compliant AIR6241 measurement system necessitates that the instrumentation (number and mass) aswell as the sampling system must be compliant.

2. Objectives of the study

The work detailed in this report is only determined with the implementing framework contract **EASA.2010.FC10 (SAMPLE III)** specific contract **SC04.**

The objective of this specific contract is to upgrade the APC to make it AIR6241 compliant.

EASA required the SAMPLE III consortium to conduct the following task in order to support the above objective:

- Task: Exchange the CPC contained in the APC with an AIR6241 compliant one.

3. Task: Exchange the CPC contained in the APC with an AIR6241 compliant one

3.1 Introduction

Task 3 of specific contract SC03 of Framework Contract EASA.2010.FC10 is to construct and validate the SAMPLEIII sampling system as an AIR6241 complaint sampling system via comparison with other AIR complaint systems.

The APC (AVL Particle Counter Advanced) owned by EASA is part of this sampling system. The CPC (Condensation Particle Counter) contained in the APC is no longer AIR complaint since it does not conform to the newest specifications defined by the SAE-E31 Committee.

Therefore the APC needs to be upgraded to make it AIR complaint. The current CPC is Model TSI 3772 and has been replaced by Model TSI 3790-E.

3.2 Replacement CPC TSI3790-E specifications

SAE AIR6241 outlines all the CPC specification requirements in Section 6.2.1.

CPC TSI Model 3790-E is based upon the CPC Model 3790 but with slight performance modifications required to meet the SAE specification.

The Model 3790 meets many of the AIR6241 CPC specifications, however, as there are significant differences between the two CPC models, TSI have provided an Addendum to the CPC Operation and Service manual to show the key instrument specifications. The manual Addendum is shown in Figures 1 & 2.

Model 3790E
Engine Exhaust
Condensation Particle Counter

Addendum to P/N 1933802 Model 3790 Operation and Service Manual

The Model 3790E Engine Exhaust Condensation Particle Counter is designed specifically for use in aircraft turbine engine emission testing applications as recommended by SAE Aerospace Information Report 6241: Procedure for Continuous Sampling and Measurement of Non-Volatile Particle Emissions from Aircraft Turbine Engines (AIR 6241). The Model 3790E functions in the same manner as the Model 3790 Engine Exhaust Condensation Particle Counter with slight performance modifications required to meet the E31 specification. As such, the Model 3790 Operation and Service Manual (P/N 1933802) should be referred to for all Warranty, Safety, Operational and Technical information.

Please note, however, that the Model 3790E operates with a different counting efficiency curve than the Model 3790. In accordance to the AIR 6241 specification the counting efficiency of the Model 3790E is >50% at 10nm and >90% at 15nm.

Note also the following table of key instrument specifications for the Model 3790E. All other specifications remain unchanged from the Model 3790.

Figure 1 CPC Manual Addendum for TSI 3790-E page 1

Model 3790E Condensation Particle Counter Key Specifications

Lower particle size characteristics as per E31	Counting efficiency >50% at 10 nm. Counting efficiency > 90% at 15 nm. Verified with DMA-classified emery oil particles as per AIR6241.
Max. detectable particle	> 3 µm
Particle concentration range .	0 to 1 × 10^4 particles/cm^3, single particle counting with continuous, live-time coincidence correction that can be turned off, as per AIR6241
Particle concentration accuracy..................................	±10% at ≤1 × 10^4 particles/cm^3 compared to standard as per AIR6241
Concentration Linearity.........	Linear response from 1 to 10^4 particles/cm^3 with coefficient of determination (R^2) ≥0.97 as per AIR6241
Calibration Method................	Calibrated against aerosol electrometer and electrostatically classified emery oil as recommended by AIR6241
Response time........................	< 5 sec to 95% in response to concentration step change
Aerosol flow rate	1000 ± 50 cm^3/min; NIST traceable
Operating temperatures	
Saturator	39°C ±0.2°C (nominal*)
Condenser.................................	22°C ±0.2°C (nominal*)
Optics......................................	40°C ±0.2°C
False background counts	0.001 particle/cm^3, based on 12-hr average

* The actual value is set to meet the AIR6241 efficiency curve specifications.

UNDERSTANDING, ACCELERATED

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Figure 2 CPC Manual Addendum for TSI 3790-E page 2

3.3 AIR6241 CPC calibration specifications

SAE AIR62421 outlines the CPC calibration requirements in Section 6.2.3.

"Calibration shall be traceable to a standard calibration method (ISO 27891): By comparison of the response of the CPC under calibration with that of a calibrated aerosol electrometer when simultaneously sampling electrostatically classified calibration particles

Calibration shall be undertaken using at least six standard concentrations spaced as uniformly as possible across the CPC's measurement range. These points will include a nominal zero concentration point produced by attaching HEPA filters, or equivalent performance, to the inlet of each instrument. With no calibration factor applied to the CPC under calibration, for the non-zero measured concentrations, the CPC shall be within ±10 per cent of the standard concentration for each concentration used. The gradient from a linear regression of the two data sets shall be calculated and recorded. A calibration *k* factor equal to the reciprocal of the gradient shall be applied to the CPC under calibration. Linearity of response is calculated as the square of the Pearson product moment correlation coefficient (R^2) of the two data sets and shall be equal to or greater than 0.97. In calculating both the gradient and R^2 the linear regression shall be forced through the origin (zero concentration on both instruments).

Calibration shall also include a check on the CPC's detection efficiency with particles of 10 nm and 15 nm electrical mobility diameter. The CPC shall have a counting efficiency of ≥50% at 10 nm and ≥90% at 15 nm.

The calibration aerosol shall be Emery oil, or an aerosol that can be shown to provide an equivalent response. For example, if the efficiency curve is measured with a different aerosol, such as soot, the correlation to the Emery Oil curve must be provided as a chart that compares the counting efficiency obtained using both test aerosols."

3.4 CPC replacement calibration

A TSI 3790-E CPC (serial number 3790132002) replaced the original TSI 3772 CPC within the AVL APC. The calibration certificate (Figure 31) shows that the replacement 3790-E CPC meets all the specifications outlined in section 3.3.

CPC MODEL 3790E CERTIFICATE OF CALIBRATION

3790132002	Serial Number
22-May-2013	Date

Test Aerosol: Emery Oil

Inlet Flow

		Units	Low Limit	High Limit
0.9986	Measured Flow (Volumetric)	L/min	0.95	1.05
0.887	Calculated Flow (Standard)	SL/min	-	-

Standard Conditions; 0° C, 101.3 kPa

Temperature and Pressure

		Units	Low Limit	High Limit
20.22	Room Temperature	ºC	-	-
44%	Room Relative Humidity	-	-	-
96.6	Room Barometric Pressure	kPa	-	-
39	Saturator Temperature	ºC	38	40
22	Condenser Temperature	ºC	20	24
40	Optics Temperature	ºC	39.8	40.2
32.3	Cabinet Temperature	ºC	20	35
86.5	Pressure Drop Across Orifice	kPa	70	88
0.624	Pressure Drop Across Nozzle	kPa	0.2	1

Laser Check

		Units	Low Limit	High Limit
17	Laser Power (Measured)	mW	14	20

Optics

		Units	Low Limit	High Limit
40	Laser Current Reading	mA	12	-
1.0	Minimum Pulse Height	V	1	3.65
320	Minimum Pulse Width	ns	230	950
3.3	Maximum Pulse Height	V	2	3.65
640	Maximum Pulse Width	ns	230	950

Zero Count Test

		Units	Low Limit	High Limit
0.0003	Concentration Average Over 12 Hours	p/cc	0	0.001

Lower Detection & Concentration Linearity Test Results

Value	Parameter	Units	Low Limit	High Limit
53.2%	10 nm Particle Counting Efficiency	-	50%	-
98.1%	15 nm Particle Counting Efficiency	-	90%	-
99.1%	Linearity Test: Slope (up to 10,000 p/cc)	-	90%	110%
0.9989	Linearity of Regression (R^2)	-	0.97	-

Final Voltage Measurements

Pass	Analog Input and Output Voltages

Linearity Response: CPC vs. Electrometer 3068B

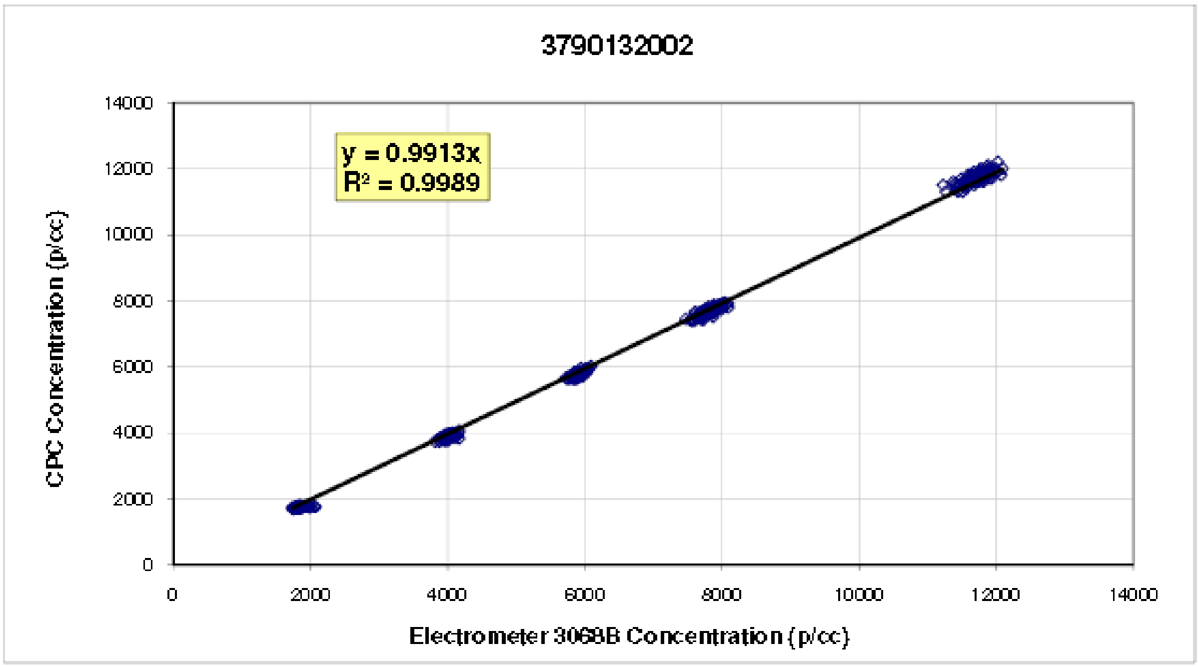
Nominal Conc.	UUT	Electrometer	%Difference	Units	Low Limit	High Limit
2000 p/cc	1751.90	1838.99	-4.74%	% Diff.	-10%	10%
4000 p/cc	3884.33	4000.24	-2.90%	% Diff.	-10%	10%
6000 p/cc	5785.10	5912.53	-2.16%	% Diff.	-10%	10%
8000 p/cc	7674.08	7797.78	-1.59%	% Diff.	-10%	10%
10000 p/cc	11713.06	11699.77	0.11%	% Diff.	-10%	10%

Particle Size Used in Linearity Test; 41 nm

Figure 31 TSI 3790-E calibration certificate within EASA owned AVL APC

Figure shows the linearity response graph and proof laboratory test quality for the specific CPC.

LINEARITY RESPONSE



TSI Incorporated does hereby certify that the above described instrument conforms to the original manufacturer's specifications (not applicable to As Found data) and has been calibrated using standards whose accuracies are traceable to the National Institute of Standards and Technology within the limitations of NIST's calibration services or have been derived from accepted values of natural physical constants or have been derived by the ratio type of self calibration techniques. The calibration ratio for this instrument is at least 1:1. TSI's calibration system meets ISO-9001:2000 and complies with ISO 10012:2003, Quality Assurance Requirements for Measuring Equipment. This report may not be reproduced, except in full, unless permission for the publication of an approved abstract is obtained in writing from the calibration organization issuing this report

Measurement Variable	System ID Number	Date Last Calibrated	Calibration Date Due
High Voltage Divider	E003452	Jan 02, 2013	Jan 02, 2014
Voltage Measurement	E001315	Jul 09, 2012	Jan 09, 2014
Electrometer	E003432	Sep 11, 2012	Sep 11, 2013
Aerosol Flow	E001132	Oct 05, 2012	Oct 05, 2013
Classifier Flow	E003574	Aug 10, 2012	Aug 10, 2013
Temperature Measurement	E003163	Jul 13, 2012	Jul 13, 2013
Barometric Pressure Gage	E001992	Apr 04, 2013	Apr 04, 2014
Temperature/Humidity Gage	E002873	Nov 08, 2012	Nov 08, 2013

Bob Plautz
Calibrated By

22-May-2013
Calibration Date

Figure 4 CPC Linearity response and Quality Assurance evidence

4. Conclusions

A summary of all of the task conclusions are presented below:

1. The EASA owned particle number measurement device within the AVL APC was upgraded to meet SAE AIR6241 specifications.
2. In conjunction with Task 3 SAMPLEIII SC03, the non-volatile number measurement in the European reference system will be SAE AIR6241 compliant.

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